Until the summer of 1898 forecasts were not issued for portions of the Dominion lying west of Manitoba, but arrangements were then made whereby telegraphic reports from stations near the Pacific coast, together with about 12 United States stations, furnished through the courtesy of the Chief of the Weather Bureau, are forwarded twice daily to Victoria, B. C., at which place the agent of the Meteorological Service is local forecast official, and now issues regular daily forecasts based on a weather chart nearly as complete as will be possible until telegraphic communication be established with more northern portions.

The Canadian Service fully appreciates the necessity of extending its system of meteorological stations over the northern part of the Continent, and we now have observations taken at Herschel Island, in the Arctic Sea,[1] Hay River, latitude —° —' north, longitude —° —' west; Fort Simpson, latitude 61° 52' north, longitude 121° 43' west; Fort Churchill, latitude 58° 51' north, longitude 94° 11' west; York Factory, latitude 57° 0' north, longitude 92° 28 west; Moose Factory, latitude 51° 16' north, longitude 80° 56' west; Martins Falls, latitude 51° 30' north, longitude 86° 30' west; Fort Chipewyan, 58° 42' north, 110° 10' west; Fort Good Hope, latitude 66° 20' north, longitude 128° 25' west; Norway House, latitude 53° 58' north, longitude 97° 52' west; and at Dawson and several other points in the Yukon. Bidaily telegraphic reports are received from Barkerville, B. C., the farthest north telegraph station on the Continent, and it is probable that in the near future Dawson may be added to the list.

It may be added that the Dominion Magnetic Observatory, now situated at Agincourt, 9 miles from the Central Meteorological Office and 6 miles from any lines of electric tramway, is under the supervision of the Director of the Meteorological Service.

AN ADVANCE IN MEASURING AND PHOTOGRAPHING SOUNDS.[2]

Prof. BENJAMIN F. SHARPE, M. A.—(Dated Greenwich, N. Y., June 1, 1899.)

THE NATURE OF THE PROBLEM.

Since the passage of sound through the air consists in alternate condensations and rarefactions, a direct measurement of the intensity of sound must measure these changes in atmospheric pressure. Practically this has been very difficult to do for two reasons: first, because these pulsations follow each other so rapidly. Middle C on the piano, for instance, has 256 condensations, each followed by a rarefaction, making 512 distinct pressure maxima and minima in a single second; evidently no ordinary instrument for measuring pressure, such as the barometer, would serve in this case. But the second and greater difficulty lies in the fact that these condensations are so exceedingly minute, being indeed from a hundred thousand to a million times smaller than the pressure differences that can be read on an excellent mercurial barometer.

Consequently the energy acting upon the ear drum in case of the faintest, audible sound is of the same order of magnitude as the energy falling upon the retina from the faintest star visible to the naked eye, a star of the 6th magnitude; while the energy of a sound of maximum intensity (at this point the ear ceases to distinguish which of two tones is the louder) is about as much as that involved in the growth of a single, ordinary blade of grass in June. So in every case we are dealing with very minute quantities of energy.[1]

There are a great variety of sounds to be measured, but for convenience we may group them all into three great classes: noises, musical notes, and pure tones. Of these pure tones are the simplest, for they consist of a definite number of pulsations per second, and the pulsations follow each other at equal intervals. A tuning fork affords a good example. If it be struck gently, it produces a faint tone, if it be struck harder a louder tone is heard, but the sound does not change in character or in pitch; only the intensity of the tone changes. If we wish to change the pitch, a fork of different dimensions must be taken. Consequently there are two measurements to be made in studying even the simplest sound, viz, loudness or intensity, and pitch or frequency, the latter being the number of pulsations per second. A musical note is some combination of pure tones, whose frequencies bear a simple ratio. But the choice of the component tones, as well as their relative intensities, determines the differences in quality or timbre, such, e. g., as the difference observed between the same note produced on the flute and on the violin. A musical note, accordingly, has to be analyzed into its component tones before the note is fully determined. We might naturally suppose that a further distinction might be made based on the differences of phase arrangement possible in a note, but it is found that the ear does not appreciate these differences, though the photographic instrument herein described makes them evident to the eye. If now we add to a note a single tone whose frequency does not bear a simple ratio to the other component tones of the note, a discordant sound or noise results. And even though a particular noise contained a hundred tones and not a single simple ratio, its complete determination would involve nothing more than the determination of the frequencies and intensities of all the component tones at the given instant. Of course these components may be continually changing from moment to moment. In fact noises are hardly ever constant in either loudness or quality, and this fact, together with the very great variety of frequencies, which the component tones may have, renders it so difficult to completely determine a noise, that as yet this has never been done. But our instrument will photograph a noise as well as any other sound, and by the aid of the photograph we may determine its principal component tones, and also the intensity of the noise.

AN INSTRUMENT TO MEASURE SOUND.

We would naturally begin with the simplest case in working toward a sound-measuring instrument, and fortunately this is also the case of the greatest physical importance, since all the theoretical laws concerning the propagation of sound assume a pure tone. To test these laws, or rather to derive

[1] Latitude, 69° 25' north; longitude, 138° 53' west, near the mouth of the McKenzie River.—ED.

[2] The work here described was done recently by the author, Prof. B. F. Sharpe, while a Fellow in Clark University, following a suggestion made by Professor Webster. A much more detailed, technical account of the apparatus and the associated mathematical theories will be published later. This general, preliminary account has been prepared for the MONTHLY WEATHER REVIEW at the request of the Editor in the belief that the instruments and methods here given will prove serviceable in certain special meteorological investigations, since the faintest waves of pressure are recorded by the apparatus.

There are many acoustic phenomena observed in the atmosphere whose analysis, with the help of proper apparatus, ought to give us methods of determining the velocity of any movement going on in the air, the temperature of the air, the disturbances produced by warm bodies, by the explosions that attend meteors, lightning, cannonading, etc., and especially those that attend the formation of rain, hail, and snow. It is not for the ordinary Weather Bureau observer to conduct these delicate investigations; they are the special province of the mathematical physicist and laboratory expert. To the latter meteorology must look for the further building up of this branch of our science. It is likely that the study of the vagaries of the sounds from fog signals, which has been prosecuted by our Lighthouse Board without the help of Professor Sharpe's ingenious apparatus, would become more precise and satisfactory if his methods could be applied to that study. Meteorology has much to hope from the proper study of sound waves, which are, in fact, only minute waves of barometric pressure and Professor Sharpe's methods take up the subject where the ordinary barograph fails on account of its sluggishness.—ED.]

[1] Wien, Ueber die Messung der Tonstärke, Berlin. 1888, p. 47.

them experimentally, we do precisely as we would in any scientific investigation, i. e., eliminate unnecessary complications, in this case by dealing with a pure tone.

A pure tone of medium pitch may be magnified forty or fifty times by receiving it in a Helmholtz resonator. This is nothing but a hollow sphere of some hard substance like brass or glass, having a hole for the tone to enter, and a small, funnel-like projection to place in the ear. Within this resonator the condensations and rarefactions may be fifty times greater than in the open air. But any cavity magnifies, though not so much, some one tone to which it resounds. A "Mellin's Food" bottle, for instance, is a resonator to a note a trifle below middle C. When its open mouth is held near the ear and its note is sung, the bottle is heard to resound very strongly. So we have taken one step toward overcoming the twofold difficulty by magnifying the infinitesimal pressures of sound by means of a resonator, carefully constructed,[1] to resound to the tone which we propose to measure. Another step is taken by causing these magnified pressures to act upon a very sensitive plate.

Here is the same principle as that involved in the telephone and phonograph. The pulsations of the air within the resonator force the plate to vibrate in close imitation; for the thin plate is made to form a part of the walls of the resonator, by cutting out a circular hole in the resonator opposite its mouth, mounting a ring on this circle, and attaching the plate to the ring. We make this step as long as possible by so choosing the substance and dimensions of this plate,[2] that its own fundamental tone when mounted is identically that of the tone to be measured. Here again we invoke the aid of the principle of resonance, which is a very powerful and far reaching principle. In this instance we obtain no further magnification of the sound motion, but we gain this great advantage, that instead of the infinitesimal motions of invisible particles of air, we have now a measurable motion of the center of a definite plate of solid substance.

Therefore we next require some optical device for observing this motion. Prof. A. A. Michelson's form of the refractometer[3] is admirably suited to our purpose. It consists of a system of mirrors by which one beam of light is separated into two beams; these travel paths differing slightly in length, so that, when they are reunited, the interference of the waves of light produces interference bands. The arrangement of the mirrors is shown in fig. 1.

B is a metal base with horizontal surface. On this the mirrors are mounted with their reflecting planes perpendicular to the surface, *B*. A beam of light comes horizontally from a lamp in the direction of *L* and encounters the half-silvered mirror, *H*, so called because it has a very thin film of silver on its shaded side. Here the beam is separated into two; one part is transmitted through the silver film toward *S*, and the other is reflected from the silver surface toward *T*. *T* is a totally reflecting mirror, its face is heavily silvered, and it is so set that the beam falling upon it from *H* is reflected back to *H* over the same path. This part of the beam penetrates the silver film of *H* and proceeds toward *O*. The other part also encounters a totally reflecting mirror at *S*, by which it is reflected back to *H* along the same path whence it came, and it is again reflected from the half-silvered mirror toward *O*. Thus, from *H* toward *O* the two beams travel the same path. But the beam going to *T* travels three times through the thickness of the glass, *H*, before arriving at *O*, while the other beam, that goes to *S*, passes through *H* only once. Consequently, there is a difference of path which would be troublesome if we did not equalize matters by introducing a compensating glass, *C*, of the same kind and thickness as *H*, and set parallel to *H*. If still there is a difference in path of an odd number of half-wave lengths between the double distances *HT* and *HS*, an observer in the direction *O*, looking toward *T*, will detect interference bands. If the light coming from *L* is the yellow light of a sodium flame, these interference bands will be alternately black and yellow; their width, shape, and direction will depend upon the orientation of the reflecting plane of the mirror, *T*, or *S*. If *S* has the direction of its plane fixed, small adjustments may be made in *T* by which we can arrange the bands to suit our purpose. Suppose we make them just wide enough so that the four black and four yellow fringes occupy the field of vision, in this case a surface equal to *S*; suppose we make the bands have straight edges and make them stand vertically in the field. If now we cause either *T* or *S* to move slowly parallel to itself, we find that a very small motion of the mirror causes a very large shifting of the bands to one side. In fact, a motion in *S* amounting to about 0.0003 mm. causes a pair of fringes to occupy the place of the next pair. Of course as much motion as this in the bands is perfectly evident to the naked eye, but by means of a telescope with micrometer eyepiece a motion in *S* of a hundredth part of that just named could be accurately measured, viz, three-millionths of a millimeter.

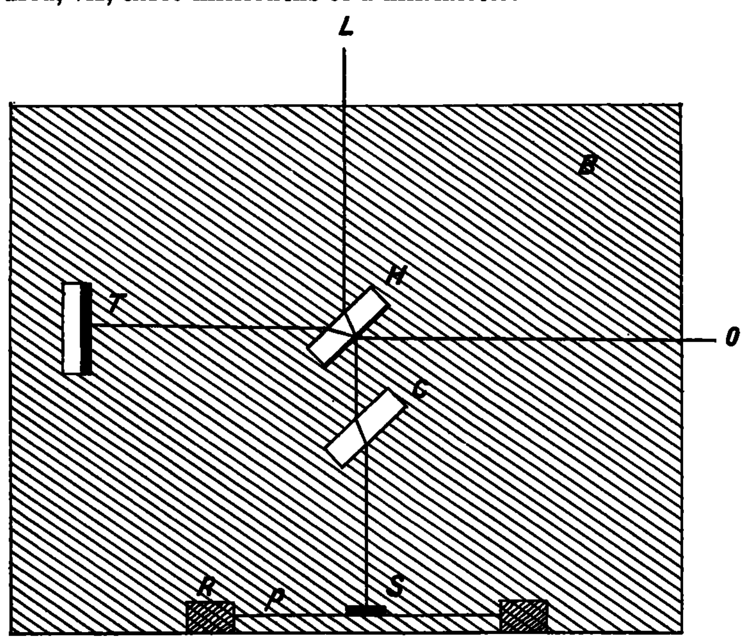


FIG. 1.—Plan of the refractometer.

Here is an extremely sensitive instrument for measuring small displacements. We will apply it to our purpose by mounting a very small and light mirror on the center of our sensitive plate, and by bringing this mirror into the position of *S*, fig. 1. The refractometer is shown in fig. 2,[1] uncovered and with its resonator removed. The little mirror is in place, and a ring, similar to the one on which the sensitive plate is mounted, lies in front. The resonator is mounted by screwing its ring into the same frame that supports the ring of the sensitive plate. A thin rubber ring serves as packing. If now the mouth of the resonator is corked, and the air within it is slightly compressed, the thin plate will bulge out a little, and the bands will be displaced, say to the right. But if the pressure within the resonator is slightly less than that without, the plate will bulge inward and the

[1] Helmholtz, Sensations of Tone. Second English edition, p. 373.

[2] Rayleigh, Theory of Sound, sec. 218.

[3] Michelson, "Interference Phenomena in a new form of Refractometer." American Journal of Science, 1882, (3), XXIII, p. 395. See also the mathematical treatment, by Professor Michelson in Philosophical Magazine, January-June, 1882, (5), XIII, p. 236.

[1] Figs. 2-12, 15, and 16 will found on Plates II, III, and IV.

bands will be displaced to the left, there being always a fixed ratio between the pressures and the motion of the bands. In this case the pressures can be measured with a water manometer.

Just here we have to meet the second part of our twofold, fundamental difficulty in measuring sound, for the pressures we have to measure in the resonator, due to sound, are not steady pressures such as we have just obtained by means of the air pump, but they are very rapidly alternating pressures, and even though our thin plate with its little mirror follows them perfectly, yet the motion of the interference bands from side to side is far too rapid for the eye to follow. But we can make the displacement of the bands a measurable quantity by aid of the simple principle of the composition of motions. To do this we place a screen in the path of the interfering light, as near to the half-silvered mirror as convenient. This screen has a narrow horizontal slit, so that the bands are cut down to a narrow strip. This viewed in the telescope appears as in the accompanying figure (fig. 3), and has a vertical height, o, measured in micrometer divisions. If now the object glass of this telescope is a small light lens mounted on the end of a tuning fork (which is electrically driven and is in such a position that the lens vibrates in a vertical line), the thin strip of bands will appear greatly elongated, as in the accompanying figure (fig. 5), for its vertical height has been stretched out by the changing refraction of the rays due to the motion of the lens, from o to Q. We have supposed thus far that no sound whatever disturbs the sensitive plate, but now we start a tone which has the same number of vibrations per second as the fork carrying the object glass. The vibrations of the little mirror, S, due to the tone, cause every point in the narrow strip to vibrate horizontally across the field, while the motion of the object glass causes every point to vibrate vertically at the same time. Consequently the composition of these two motions *may* result in an oblique line for each point, and the image of the bands *may* appear in the telescope as shown in fig. 6. In this figure the displacement, P, due to sound, is three and a half double bands; and it is related to a, the slope of the bands, in such a way that $P = B \tan a$, in which $B = Q - o$.

A louder tone causes a wider displacement, P, and if the elements incidentally involved in the measurement remain constant, then the intensity of the tone will be proportional to P^2. This is equal to $B^2 \tan^2 a$; hence, what we actually measure are o, Q, a, and the width of a band; so that P is determined in wave lengths of light. The eyepiece is specially constructed to measure angles, as well as lines in any direction. The displacements, combined with a knowledge of the pressures within the resonator necessary to produce them, give the intensity of sound in an absolute measure, i. e., in ordinary units of energy, such as ergs or foot-pounds. More exactly, it may be stated, that the motion of the little mirror fixed on the sensitive plate is calibrated in terms of pressures within the resonator, by means of comparison with the motion of a second plate of high pitch on which a steady pressure acts. This is necessary, because the rythmic pressure of a tone, well-timed to the natural oscillations of the plate, produces far greater displacements than a steady pressure of the same amount; just as a horse in trotting may give a bridge so much motion as to endanger it, while the weight of the horse standing still would produce no apparent bending. But if the second plate is only four octaves higher in natural pitch than the tone measured, the pressure may be measured statically with an error of less than four parts in a thousand. The mathematical theory by which these observations are made to yield an absolute measure of the intensity of a sound is a modification of that employed by Wien[1] for a similar purpose.

[1] Wiedemann Annalen, 1889, p. 835.

INCIDENTAL DIFFICULTIES OVERCOME.

The two fundamental difficulties have now been entirely removed. We have magnified the sound pressures and the displacements which they produce in spots of light, until the former can be accurately measured by means of the latter. But meanwhile we have met three incidental difficulties, each so serious as to threaten us with defeat. One of these is a little matter of difference in phase. It is stated above that the appearance of the image due to the double motion may be like that represented in fig. 5. But as a matter of fact the probabilities are very largely against its so appearing. For the composition of the double motion of the light and dark spots of fig. 3 into the straight lines of fig. 5 is due to the fact that a spot begins its motion to the right, for example, at the same instant that it begins to move downward. This is agreement in phase, for both of these independent motions are harmonic, or pendular. So, if we see fig. 5 in the telescope, it is because the source of sound is just far enough distant for a sound impulse to act upon the sensitive plate as the object glass is beginning one of its swings. But if the source of sound is moved a little from this position the two motions will be out of phase; and accordingly each spot of the strip will describe an ellipse of eccentricity depending on the phase difference, just as in the familiar case of Lissajous's figures for forks in unison. Evidently a very small amount of eccentricity will make the ellipses overlap and blur the edges of the oblique bands so completely that we can not set the spider line of our eye piece to the slope of the bands. Of course, a motion in the source of sound of less than a wave length of the tone may bring the two vibrations into phase again. But in a room, where such investigations are usually carried on, the reflections of sound from ceiling, floor, and walls, cause an additional disturbance in the form of standing waves, and consequently we would have to move the source of sound about in the three directions while seeking the positions that would give agreement in phase. This is extremely laborious, and thoroughly unsatisfactory; moreover it unduly limits the usefulness of the instrument. The phase of the object glass, on the other hand, may be varied by means of an adjustable self-induction (thrusting an iron core into a coil of wire in the circuit by which the tuning fork is driven) and in some other ways; but these variations are insufficient for all cases, and are therefore unsatisfactory. What we will do, then, is to make the tone and object glass differ slightly in frequency, by putting a small load, e. g., of adhesive wax, on the tines of the fork carrying the object glass. In this way we make the phases of the one oscillation overtake those of the other as slowly as we please; then in the telescope we will observe the bands sloping downward to the left, as in fig. 5, and after an interval of two or three minutes the bands will have the same slope downward to the right. Between these appearances confusion will reign, for during the interval the field is occupied by overlapping ellipses. But there is abundant time to make a careful measurement of the angle of slope at either extreme position, i. e., when the phases are identical, and when they are opposite. The angle in each case will be the same if only the tone is constant in intensity.

Another of these incidental difficulties was how to get a plate thin enough to be sensitive, homogeneous enough to vibrate in a symmetrical manner, and elastic enough to come to rest always in the same position. Ten substances were investigated without success, when finally the thinnest cover glass, for use with the microscope, was found to be satisfactory. Thus far glass has been employed as the most available substance for thin plates, though either steel, or gold of 14 karats, promises ultimately to prove superior.

AN INSTRUMENT TO PRODUCE PURE TONE.

A third incidental difficulty was a suitable source of sound, for we must produce our sounds as well as measure them. To investigate the fundamental laws of sound, it is important that our source produce a pure tone of very great constancy in pitch and in intensity. Besides, we must be able to vary its intensity at will between wide limits. Moreover, the source should afford a very definite point from which to measure its distance to the resonator of the refractometer. And, finally, the source should be very portable, so that this distance may be varied at will. No such instrument exists, so we must construct one. A tuning fork makes a good beginning, for it is very constant in pitch or frequency, and also tolerably pure in tone, its overtones being relatively weak. Moreover, the inertia of a heavy fork tends greatly to make its tone constant in intensity. But a fork alone will not serve our purpose, for at best we can not make a very loud sound with it, its overtones are somewhat objectionable, and there is no one spot whence the sound originates. So we will select a place on the fork which has a simple vibration and transmit its motion to a thin iron plate. This is done by fastening one end of a wire to the middle of the fork, which is a node for the fork's overtones, and fastening the other end of the wire to the center of the plate. The direction of the wire is the same as that of the motion of the fork, and perpendicular to the plate, so that the center of the plate is forced to vibrate exactly as the middle of the fork. But the plate itself is likely to have some overtones, so we will filter these out and greatly intensify the pure tone by making the plate a portion of the walls of another Helmholtz resonator, made and tuned to resound to the very tone which we propose to measure, which will be also the tone of the fork connected with it. This arrangement makes a very pure and effective source of sound. Simply tapping the fork with the finger makes a pretty loud sound, and the mouth of the resonator affords a definite center from which to measure distances; when in use a heavy padded box covers this instrument, excepting the mouth of the resonator, so that the tone emerges from the mouth only. A constant tone is produced by driving the fork electrically by a constant current. The intensity of the tone will depend on the strength of the current, which we can regulate at will. Moreover, the intensity of the sound can be defined in terms of the current effective in producing it. In other words the current can be calibrated in terms of the absolute intensities of the sound produced. This is done by means of the damping factors of the arrangement. The mathematical theory of this source of sound as an absolute measure is really only an extension of that given by Lord Rayleigh[1] for the tuning fork.

SOME USES FOR THESE INSTRUMENTS.

If we assume that the ear is constant and reliable we may employ it instead of the refractometer arrangement in connection with our source of sound in many important investigations. For example, we may investigate the variation of intensity with distance under various atmospheric conditions. To do this we place our source in a smooth open field when the air is free from wind and noise, produce a tone of small intensity and gradually withdraw until it is just audible; then we increase the intensity and again withdraw until it is just audible. This is repeated several times until we have withdrawn to the verge of audibility of the loudest pure tone which our instrument produces. Then a comparison of the intensities of the tone, with the corresponding distances of audibility will give the law that we seek. After such a law is established the distance at which two different persons can detect the same tone will give a numerical measure of their sense of hearing; and similarly the hearing of the two ears of the same person can be compared by stopping carefully one ear at a time. Tests of the hearing of a person in various mental and physiological conditions, as also for sounds of different pitch can be made. Moreover, the smallest change of intensity appreciable by the ear can be determined throughout a considerable range of initial intensities. By varying the intensity of the source, so that bare audibility is reached, we may likewise study problems of sound shadows, reflections, refractions, and (with two such sources, or a single source obstructed by a large building) interference. Thus our tone source may be of use both in the physiological and physical laboratories. By submerging this instrument in lake or sea, similar problems may be solved for water as the medium of sound.' Of course we shall require one such instrument for every tone which we propose to use, though simply weighting the tuning fork gives a small range of frequency, sufficient to be appreciable as pitch.

But if, instead of using the ear, we eliminate its imperfections by using our receiving and measuring apparatus, we may solve a very large number of acoustical problems with great precision. In addition to those mentioned we may suggest: the distribution of sound in a large room, as well as the natural pitch and echo of the room; the wave lengths of various tones; combinational and differential tones; the viscosity of the air; the energy of the faintest tone that is audible. Considerable pains must be taken to prevent disturbing sounds from affecting the action of the sensitive plate. These sounds are transmitted both through the air and through the floor and supports. Insofar as they originate in our apparatus, we prevent them by employing tight, heavy boxes for coverings, and soft rubber piers for supports. Other sounds which come from the building or street can not be avoided altogether, except by working in the middle of a calm night. But even the tone to be measured should not have access to the side of the sensitive plate which bears the little mirror. Consequently the refractometer itself must be carefully boxed, so that only the mouth portion of the resonator protrudes; the refractometer also rests upon rubber piers.

ILLUMINATION.

Thus far it has been assumed that the light passing through the train of mirrors of the refractometer, and forming the interference bands viewed in the telescope, has its origin in a sodium flame. But, as a matter of fact, white light is used because of its greater intensity. Consequently the bands are not quite so simple as described, but instead of being alternately yellow and black, they are a series of rainbows with two black bands in the middle of the series. Elsewhere the very dark reds and blues serve the purpose of the black bands and afford a strong contrast to the brighter colors. In computation, of course, a mean wave length of light is employed. The source of the white light is a Welsbach gas lamp. It is very intense, constant, and quiet and serves the purpose excellently. No doubt an acetylene lamp would be convenient and satisfactory for out-of-door work.

A CAMERA TO PHOTOGRAPH SOUNDS.

For photographing sounds a good electric arc lamp is required, because the time of exposure is extremely short. Indeed the arrangement is quite different from the one used thus far in direct observation. The photographic film does not precisely take the place of the retina of the eye—but the telescope with its vibrating object glass is removed, and a single fixed lens is substituted, which focuses the interference bands upon the film. This film is wound about a horizontal cylinder kept in constant and rapid rotation, as was attempted

[1] Phil. Mag., 1894, p. 365.

by Raps.[1] Here again we make use of the principle of the composition of motions. Only in this case we have added to the lateral vibration of the bands, due to sound, a steady motion in the vertical direction, instead of an oscillatory one up and down. Consequently the result is different. The screen with the narrow horizontal slit is now set as close as convenient to the film, so that, with the cylinder at rest, and with no sound, a strip like fig. 11, only very much smaller, is focused on the film. If now the cylinder rotates, this strip will be continuously printed on the film, the result being parallel bands with straight edges, like the photograph of quiet, fig. 11. But any sound added now will cause a vibration of the points of the strip sidewise, and the result will be a set of parallel, wavy bands, such as in fig. 15 and fig. 16.

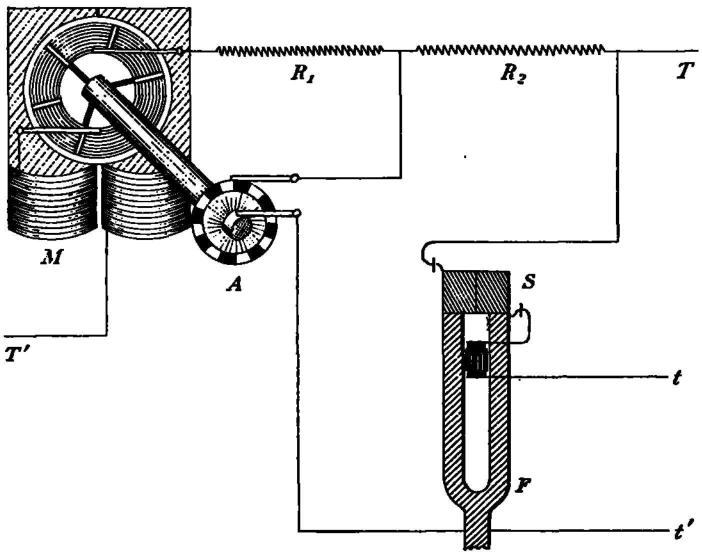


FIG. 13—Device for regulating the speed of the motor.

The accompanying fig. 12 shows the inside of the camera. The lid has been removed and the back let down. The cylinder is shown belted to a small dynamo, which is almost completely covered with black cloth to prevent its sparking from fogging the film. But the pulley is shown, with black and white sectors upon its face. This is part of a stroboscopic device to observe and regulate the speed of the motor. Opposite this disk is a ruby glass window in the camera, for the purpose of viewing the disk. But this inspection is made between the tines of another tuning fork in vibration, as shown in fig. 13. Two little screens, *S*, are fastened to the ends of the tines in such a way that they barely meet when the fork is still, but in vibration, slide over each other without touching. Thus the view is interrupted once during each complete vibration. Now, if the disk turns just fast enough for one of the black sectors to advance to the position of the next, during the interval that the screens are closed, of course the disk will appear to be at rest. This rate of motion is secured by feeding the motor with a constant current of just the right strength. This again is no easy matter, but a continental scientist, Lebedew,[2] only a short time ago, devised a method of accomplishing it satisfactorily. His method consists in the arrangement shown in fig. 13. The current through the motor enters at T and passes out at T^1. In so doing it passes constantly through the resistance, R_1, which is not quite large enough to slow down the motor as much as desired. R_2 is a second resistance, which, added to R_1, would slow down the motor too much. But a shunt, through the tuning fork, cuts out R_2 periodically, that is, for a portion of each fork period, thus bringing down the average resistance to the required amount; for the shunt circuit is regularly opened and closed at two places: at the upper platinum connection on the fork, and again at the accessory commutator, *A*, of the dynamo. If the shunt is closed at both places during the same interval, evidently R_2 is shunted out during this interval, and the motor gains in speed. But if the connection is broken at one or the other of these two places during the entire period of a fork vibration, then the current must pass through both resistances, R_1+R_2, and the motor is slowed down. Accordingly an automatic balance can be found between these two tendencies, by adjusting R_1, R_2, and the platinum contact, such as will give constantly the speed desired. The regulation is automatic, because the acceleration of the motor itself puts in more resistance, and vice versa. The fork, *F*, is driven by an independent current, and is provided with a box having glass windows, as in the case of the fork of the object glass. By suitable pulleys, a speed of about three revolutions per second is given to the cylinder, and since the shutter slit is less than a half millimeter in vertical width, and the cylinder is 50 centimeters in circumference, it is evident that the time of exposure is less than one three-thousandth of a second; consequently a very intense light is required.

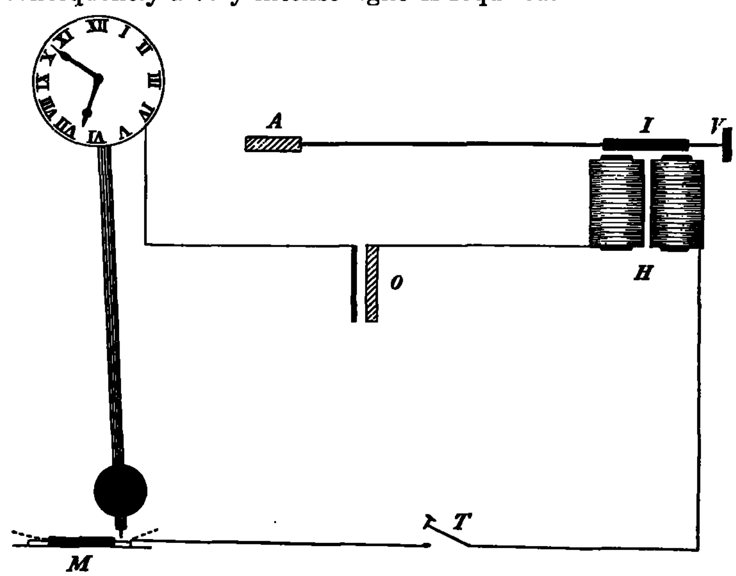


FIG. 14.—Device for opening the shutter.

But the time of exposure differs from the time that the shutter is open, for during this interval a series of pictures of the size of the shutter has to be made entirely around the cylinder, unless we wish to waste our film by blank spaces, or by overlapping pictures. It is therefore, desirable that we make the shutter open for precisely a third of a second at each exposure. This is done by the device represented in fig. 14. The shutter, *A*, is at the end of a long lever, operated by an electro-magnet, *H*. The armature, *I*, has a hinge motion by means of the thin, flat spring, *V*, which is firmly clamped at the end represented toward the right-hand of the figure. The current from the battery, *O*, passes down the pendulum of the clock, which beats seconds, and around through the electro-magnet, provided that the platinum point of the pendulum happens to be passing through the mercury, *M*, and provided also that the key, *T*, is closed. We adjust the width of *M* so that the pendulum is in contact with it during about half of one swing; then, to make an exposure we close the key at the beginning of a swing in either direction, taking care to open the key when the swing is completed. This is best done by having the clock where we can see it. The ticking is no disturbance, for it dies away before the shutter is opened.

THE UTILITY OF A CAMERA FOR SOUNDS.

With such a camera we may photograph sounds of any

[1] Wied. Ann., 1893, Band 50, p. 194.
[2] Wied. Ann., 1896, Band 59, p. 118.

sort. Fig. 15 gives a number of photographs of tones and combinations of tones. The straight, narrow, white line along the middle of each photograph is produced by the shadow of a fine wire, stretched vertically across the middle of the narrow slit of the camera. This line is not shifted with the bands, so it affords a convenient position from which to measure the displacements of the bands. When picture No. 1, fig. 15, was taken the room was very quiet, so far as the ear could discern. But it appears that the instrument was more sensitive than the ear, for otherwise these lines would have been as straight as the reference line. Instead they show small oscillations of the little mirror, and therefore a sound is revealed. A strong tone causes a wide displacement, like No. 12, while a weak tone causes less displacement, as in No. 13. If the tone is high in pitch, the wave length is short, like No. 8, but a low tone gives a long wave, like No. 6. By comparing the number of waves in a given length we find that the flageolet was blown on F in the fourth octave above No. 6. This fact could not be determined by the ear. Again the flageolet was blown with utmost intensity and produced a painfully loud and shrill sound, while the tuning-fork of No. 6 was touched very gently and its tone sounded very faint to the ear. Yet the displacements are evidently much larger than in No. 5, and accordingly a tone of low pitch has in it more energy than one of high pitch, since the energy is proportional to the square of the displacement; hence the ear must be more sensitive to high tones. In taking all these pictures the influence of the resonator was eliminated by removing the resonator. This was done by simply screwing it off and leaving only the sensitive plate. It was desirable to know the natural pitch of this plate loaded with the little mirror. This was accomplished by opening the shutter of the camera just after fanning the plate once gently. The motion of the air displaced the plate slightly, and in coming to rest it swung to and fro in its own natural period. This is shown well in No. 3, and by counting and comparing wave-lengths again we find its pitch is G flat, or about 186 vibrations per second. The record begins on the right-hand of each figure, and the motion was at first somewhat irregular, because the air near the sensitive plate was still disturbed by the fanning. But it appears that, as we proceed to the left, the plate soon settles down to a regular motion. This photograph is selected to show how this motion begins, and is taken from a film twenty inches long. It would appear from the pictures produced by tuning forks sounding together that a discord, like No. 11, gives sharp waves, while for forks in harmony the combined waves are round and smooth, as in No. 12. The perfection of our source of tone is shown in No. 13.

It will assist in forming a conception of what is represented in these photographs, if we place these long bars in a vertical position before the face. Then, if the film were at rest, and if the exposure was extremely short, the picture of the interference bands would be like a strip cut out horizontally across one of these bars, less than a half millimeter in vertical height. The picture contains the exact position of the interference bands at that instant. Now, suppose the film is moving rapidly upward. At each successive instant the photographic film records the changing position of the bands, because the vertical position of the strip on the film is changing simultaneously. Consequently, each photograph is a chart, showing continuously the changes in atmospheric pressure due to sound.

The cylinder covered with the film is moved along in the direction of its axis after each complete photograph, by turning up the screw shown in connection with the camera. Its handle projects to the right, and its point bears against the base of the carriage which carries both cylinder and motor. This carriage slides smoothly and easily upon the base of the camera, by the motion of the screw, without opening the camera or stopping the motor. With this apparatus 10 feet of such sound photographs have been taken in as many minutes with a simple arrangement for winding a long, narrow film continuously from one cylinder upon another, a similar photograph may be taken of an entire oratorio or address.

Fig. 16 represents photographs of the vowel sounds occurring in the words indicated.[1] These vowels were sung by the author as distinctly as possible, but rather softly, upon the note an octave below middle C, or upon the C, having 128 vibrations per second. The resonator had been removed, as before, so that the sound waves acted directly upon the sensitive plate. Each vowel is represented by seven complete waves. The degree of smoothness of utterance in each case is shown by the uniformity of these waves. Ideally, every wave in each curve should be exactly alike, though each curve should be characteristic of the vowel. Of course, the height of the waves may change, for that depends simply on loudness. The length of the waves depends on the pitch on which they are uttered, and that may change too, as indeed it does, in the inflections of speech. Moreover, since different people have individual peculiarities of speech, so that they do not pronounce the same vowel exactly alike, these vowel curves are actually somewhat different in other respects also, for different people, and even for the same person under different conditions, mental and physiological.

THE ANALYSIS OF PHOTOGRAPHS OF SOUND.

The analysis of vowel curves shows that their characteristic differences consist in the relative predominence of one or more overtones. But this statement should not lead any one to make a crucial test by attempting to construct a vowel by any combination of notes on any musical instrument. For each note is itself a whole symphony of overtones, and any addition of them would be haphazard. But even a carefully studied combination of tuning forks, though it affords a recognizable vowel in the simpler cases, is subject to some limitations, so that it would not sound entirely human.[2] It seems then that the synthesis[3] of vowels is practically more difficult than their analysis. A number of very complicated machines have been constructed for analysis.[4] A recent one, by Professor Michelson, separates a curve into 80 harmonic components.[5] To prepare one of our vowel curves for his "Harmonic Analyzer" we would enlarge it considerably, e. g., by projection with the lantern, trace it on sheet metal and cut it out. The wavy edge is then fed into his machine, and for a result we obtain numbers representing the proportional strength of the first 80 overtones. A wonderful machine!

From any of our sound photographs a measurement can be made of the intensity of sound, on virtually the same plan as the one already mentioned, that is by the displacement of a given band from its mean position. This displacement is read by means of a micrometer microscope applied to the film itself, or by means of a lantern projection. We have already ascertained that each displacement of the bands corresponds to a definite motion of the sensitive plate which carries the little mirror. A mathematical relation connects this motion with the condensation of the air within the resonator, another relation connects the condensations within with those without; so that, thus, there is a complete chain of relations,

[1] Cf. Hermann's work, Phonophotographische Untersuchungen. Bände 53, 58, 61, Archiv für Physiologie.
[2] Helmholtz, Sensations of Tone. Note by Ellis. p. 543.
[3] Preece and Stroh. Proc. Roy. Soc. Vol. XXVIII, p. 358.
[4] Jenkin and Ewing. Trans. Roy. Soc. Edinb. Vol. XXVIII, p. 745.
[5] A. A. Michelson and S. W. Stratton. A New Harmonic Analyzer. Am. Jour. Sci., January, 1896, (4) V, pp. 1-13; also L. E. D., Phil. Mag., January, 1898, (5), XLV, pp. 85-91.

having at one end the displacement of the bands, and at the other the energy in the sound.

Besides all the various physical and physiological problems before mentioned in this paper, whose data may be obtained in permanent records, some additional ones may be attacked with this photographic apparatus. For instance, it will be of interest to know why the same note on two different musical instruments, e. g., violin and flute, should be so different in quality. The comparison of photographs of these sounds would answer the question. Similarly we may investigate the physical peculiarities of any sound produced by man or in nature.

RAINFALL AND TEMPERATURE IN NICARAGUA.

By A. P. DAVIS, Hydrographer, United States Geological Survey.

The Nicaragua Canal Commission made certain investigations of the climatology of Nicaragua in 1898. Their observations, being confined to data bearing upon the problem of an interoceanic canal, did not include barometric investigations. Rainfall, temperature, and humidity observations were made at a number of stations, mostly in the vicinity of the proposed canal line, and well distributed between the Atlantic and Pacific. The form of rain gage used at most of the stations was a metal funnel, which caught the rain and discharged it into a bottle, from which it was measured in a graduated glass bearing a known relation to the diameter of the funnel. The gage was always placed in a position as exposed as possible; but nearly always this was a small clearing in the forest, which was still well sheltered from the wind.

One of the most remarkable characteristics of Nicaragua is its rainfall and the radical and striking differences in amount and distribution of precipitation on the east and west coasts. From the rainfall tables it will be seen that at Greytown, on the Rio Deseado, and other points near the Atlantic there is no definite dry season, but that rain may be expected any day in the year, and the expectation will seldom be disappointed. On the Pacific coast, on the contrary, there is no rain from the beginning of the record in January until the middle of May, when the rainy season begins, after which it is subject to violent downpours throughout the rainy season, the precipitation for a single day observed at Brito, on the 23d day of May, being 5.06 inches.

No less remarkable is the excessive aggregate of rainfall in a limited district of which the nucleus seeme to be in the vicinity of Greytown. The annual rainfall at this point, as deduced from the mean of four years' observation, is about 250 inches, while that at Bluefields is only about 90 inches, at Port Limon somewhat less, and at San Jose de Costa Rica about 68.

While there is a slight increase of rainfall with altitude at the headwaters of the Deseado and San Francisco, yet, in general, it may be said that the rainfall decreases as we pass up the San Juan River. No definite limit can be assigned, with present information, to this district of excessive rainfall, nor is it known in what ratio precipitation decreases to the northward and southward.

The dividing line between the characteristic climates of the east and west is not definite, but may be said, in general, to approximately coincide with the range of mountains known in canal literature as "the Eastern Divide." The portion west of this divide partakes of the characteristics of the Pacific slope, having a comparatively moderate precipitation and a definite division of rainy and dry seasons, while the territory east of this divide has no well-defined dry season and has much heavier rainfall than the west side. The exception to this rule is the valley of the San Juan. As we proceed up this river the rainfall decreases rapidly and almost uniformly, but the dry season is by no means well defined and rain may be expected in any month.

Thus, so far as quantity and distribution of rainfall alone is concerned, the conditions are rather unfavorable to the requirements of the canal. The heaviest engineering constructions are to be on the east side, where the rain is excessive and persistent, thus interferring with construction and with the permanence of the works. On the other hand, the entire basin of Lake Nicaragua, upon which the canal must depend for its water supply, is affected by a long, dry season, in which evaporation from the lake is greatly in excess of the inflow, and storage must be provided to overcome this drain.

On the west side, including the basin of Lake Nicaragua, the dry season begins in December and ends in May—being ordinarily from one to two months shorter than the rainy season. During the latter part of the dry season the inflow to the lake becomes very slight, many of the tributaries, though wide and deep, are filled with stagnant water, upon which grows enormous masses of floating vegetation, which discolors the water, renders it foul, and obstructs navigation. When the rains begin in May or June these streams are swollen to almost torrential proportions and flow with strong currents far out into the lake, carrying great masses of vegetation or floating islands, sometimes acres in extent, which form large crescents around the mouths of the streams and become a source of serious annoyance to the steamers plying on the lake. These floating islands are eventually broken up by the winds and waves of the lake, and such parts as are not discharged through the San Juan River decay in the lake.

Records of rainfall for numerous stations in Nicaragua were published by Mr. A. J. Henry in the MONTHLY WEATHER REVIEW for July, 1898, pages 304–306. Since that date some additional information has been received, making a complete record of nineteen years at Rivas and four years at Greytown. The Rivas record is from 1880 to 1898, inclusive, and the Greytown record is for the years 1890, 1891, 1892, and 1898. The contrast of climatic conditions on the two sides of the Isthmus is further illustrated by an examination of these records. The year 1890 shows the smallest precipitation of any of the nineteen years recorded, being only 31.80 inches, while in the same year 296.94 inches fell at Greytown, this being the maximum observed at that point. In the year 1898 the precipitation at Greytown was 201.64 inches, the lowest in the record, while at Rivas in that year 108.06 inches fell, this being one of the highest in the Rivas record. These facts suggest that perhaps there is a compensating influence at work and that the same cause which produces a year of small precipitation on one side operates in the reverse direction on the other.

Monthly rainfall in Nicaragua during 1898.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
Brito	.25	.00	.08	.08	11.30	14.86	11.42	6.18	16.82	25.70	6.01	2.41	95.11
Las Lajas	.25	.05	1.34	.28	10.60	13.50	10.64	8.44	6.79	16.19	4.41	2.26	74.75
Rio Viejo	.04	.01	.66	.00	13.78	13.45	4.01	11.66	7.28	8.99	0.61	0.17	60.66
Tipitapa	.26	.00	.26	.00	8.56	16.88	6.24	7.82	11.25	7.12	0.93	0.17	59.49
Morrito	.....	.....	.....	.07	8.92	14.05	13.84	10.20	.....	.....	.....	.....	.....
Fort San Carlos	.....	.....	1.21	3.00	8.22	15.56	13.35	8.00	10.56	8.93	9.86	5.62	84.31
Sabalos	.....	.....	2.10	6.00	11.69	17.13	20.69	11.33	11.42	11.81	12.17	10.20	104.54
Castillo	.....	.....	.....	.....	.....	.....	18.92	11.46	16.22	2.99	14.04	11.64	.....
Machuca	.....	.....	.....	.....	.....	.....	.....	6.52	12.86	9.83	15.65	.....	.....
Rio San Carlos	.....	.....	7.52	11.67	20.18	20.73	18.26	11.68	.....	.....	.....	.....	.....
Ochoa	13.07	14.07	8.04	12.22	15.24	21.44	21.58	12.06	15.12	8.02	21.50	8.88	170.74
San Francisco*	15.83	18.43	8.72	11.25	13.87	18.87	19.22	13.45	10.95	9.09	22.38	10.61	172.17
Sarapiqui	.....	.....	.....	.....	.....	.....	.....	.....	11.19	11.35	18.63	7.12	.....
Deseado†	21.92	26.98	11.76	8.83	14.84	18.66	26.86	13.31	5.23	11.92	29.25	21.07	210.63
Greytown	19.44	25.17	10.16	7.82	9.37	19.52	24.63	16.38	7.24	12.50	32.35	17.06	201.64

*Record incomplete from January 1 to 5, inclusive, and from December 29 to 31, inclusive, so the rainfall at Ochoa for those days is added.

†Rainfall not observed from December 25 to 31, inclusive, so the record was completed by including the corresponding days for 1897.

TEMPERATURE AND RELATIVE HUMIDITY.

The temperature of Nicaragua is remarkably uniform.

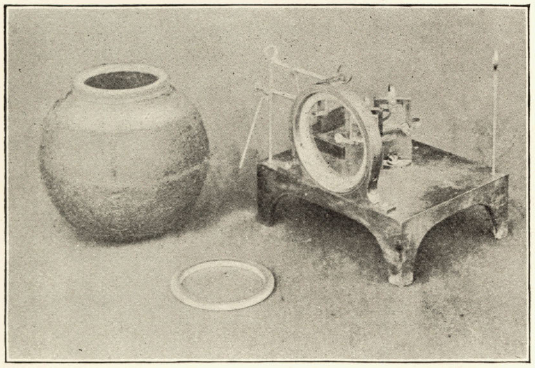


Fig. 2.—The refractometer.

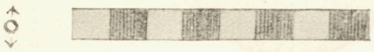


Fig. 3.—Strip of interference bands.

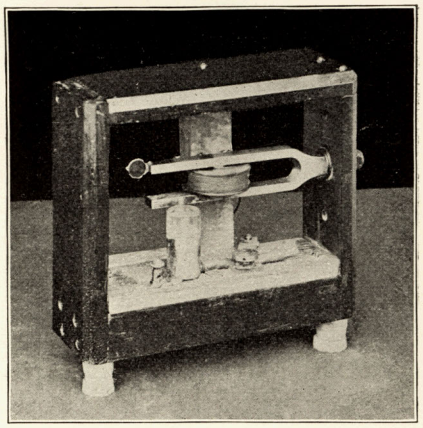


Fig. 4.—Object glass of the telescope, showing heavy frame, electro-magnet, mercury connection, and rubber supports.

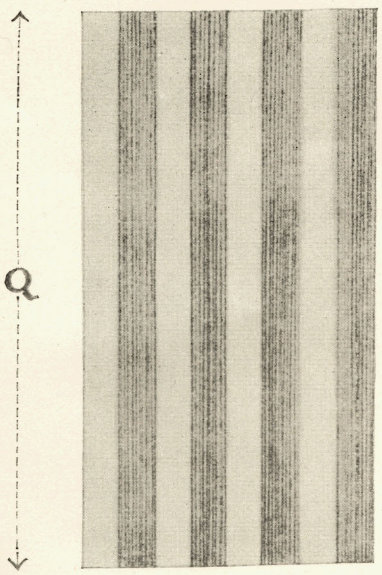


Fig. 5.—Strip of bands elongated by the vibration of the object glass.

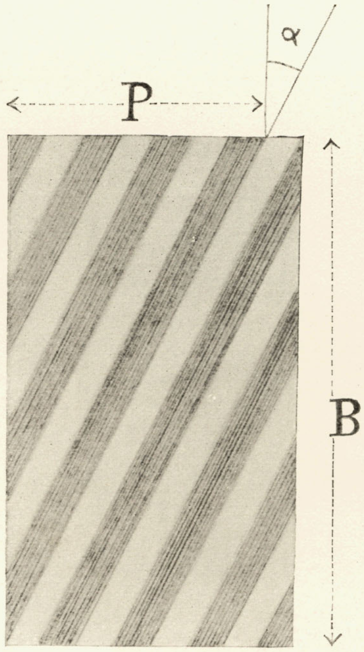


Fig. 6.—The effect of the vibrating object glass upon the elongated bands.

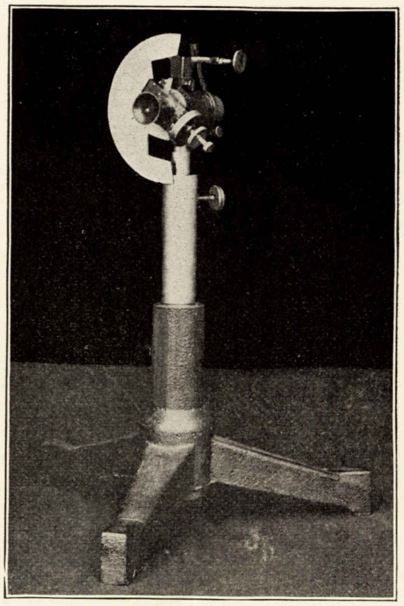


Fig. 7.—Micrometer eyepiece, rotating on its optical axis to measure angles, and provided with tangent screw.

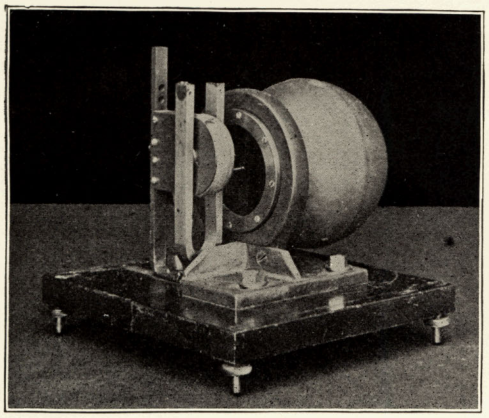


Fig. 8.—The source of tone with the box removed.

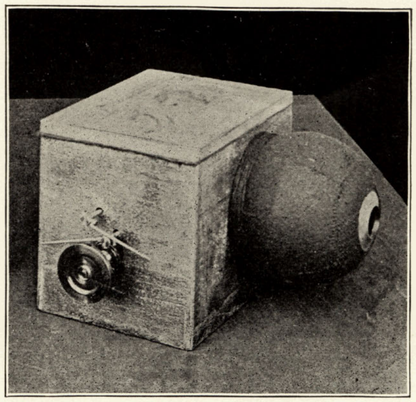


Fig. 9.—Refractometer, boxed and ready for use. The resonator is covered with felt. The screws and levers adjust the mirror, *T*.

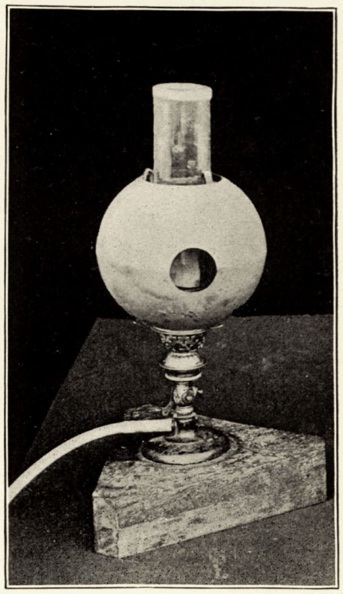


Fig. 10.—Welsbach lamp, with metal globe to confine and concentrate the light.

Fig. 11.—The image of the interference bands focused on the film, but greatly enlarged in the figure.

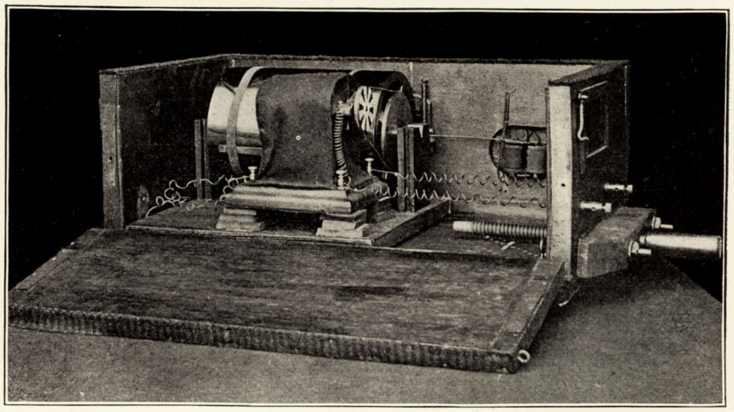
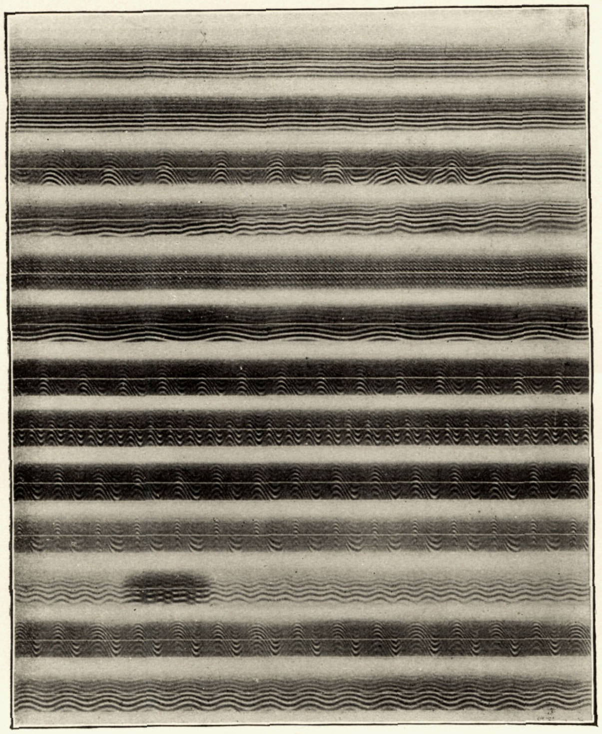
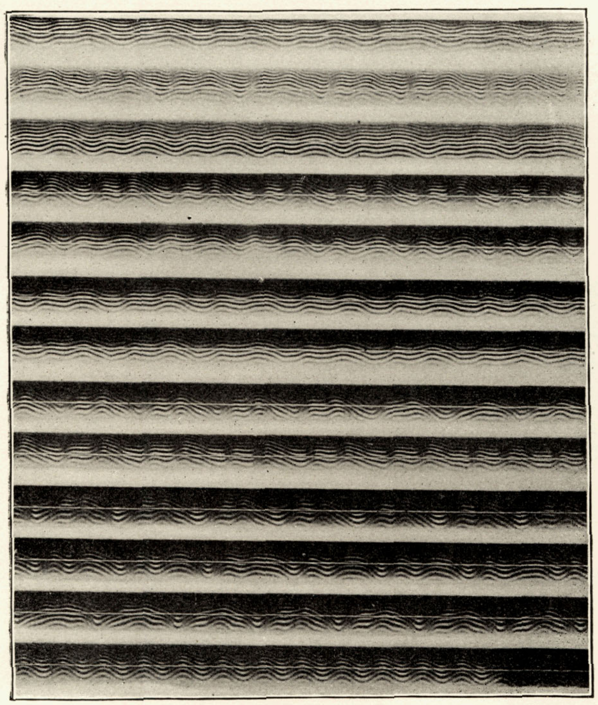


Fig. 12.—The camera, with shutter and lens turned away.



1. Quiet.
2. Fanning I.
3. Fanning II.
4. Noise.
5. Flageolet.
6. Fork C_{128}.
7. Fork c_{256}.
8. Fork c'_{512}.
9. Forks C + c.
10. Forks C + c + c′.
11. Forks g + a.
12. Forks c + e + g + c′.
13. Tone source.

FIG. 15.—Photographs of pure tones and combinations of tones.



1. (a)h.
2. (o)h.
3. p(oo)l.
4. (a)te.
5. m(ee)t.
6. s(e)t.
7. (a)t.
8. (i)t.
9. (au)ght.
10. (e)re.
11. (u)se.
12. (u)rn.
13. Fork c_{256}.

FIG. 16.—Photographs of vowels.